BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B70 03057

SUBJECT: Effect of LM Descent Stage Payload Weight Changes on Usable Propellants - Case 320

DATE: March 13, 1970

FROM: D. M. Duty

ABSTRACT

The addition of weight to LM payloads, such as the Lunar Roving Vehicle (LRV), results in shifting the LM center of gravity (C.G.), which either increases or decreases usable descent propellants. The cost or benefit to total LM payload capability due to C.G. shift is calculated for the four possible cases associated with the Apollo J-Mission payload configuration. For the case where usable fuel and oxidizer are increased, adding one pound increases LM payload capability 0.35 pounds, while the case where both usable oxidizer and fuel are decreased the cost is 0.59 pounds of payload capability. The addition of one pound to the LRV increases usable fuel but decreases usable oxidizer which results in a payload capability loss of 0.41 pounds.

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MEMORANDUM FOR FILE

INTRODUCTION

The effect of adding weight to LM payloads such as the Lunar Roving Vehicle (LRV) on Descent Stage (D/S) usable propellants is discussed in this memorandum. The primary effect of adding weight in any of the payload quadrants is to shift the LM C.G. location. This shift may increase or decrease usable propellants, depending on the initial C.G. location and where the weight is added.

PROPELLANT SUBSYSTEM

The D/S propellant subsystem configuration contains two fuel and two oxidizer tanks balanced on the Z and Y axes, respectively. The tanks are emptied simultaneously through branch feed lines to a common feed line to the descent engine. Under ideal conditions, all tanks maintain a balanced condition such that at engine shut down unusable propellants remaining in the tanks would be at their minimum values - a function of tank bottom geometry.

The control system attempts at all times to keep the descent engine thrust vector passing through the vehicle C.G. If the C.G. does not fall on the vehicle X-axis (center line), the vehicle assumes an attitude error as determined by the control system. This causes a small delta head to exist between complimentary oxidizer and/or fuel tanks depending on the new C.G. location. A differential flow will then exist, and result in the uncovering of one tank low level sensor before the other. The tank bottom and vehicle attitude geometry which causes propellant to favor one side of the tanks may add to the early occurrence of sensor uncovering. These conditions decrease usable descent propellants. GAEC is currently using C.G. cost numbers of 43 pounds of unusable oxidizer per inch of Y offset and 20 pounds of unusable fuel per inch of Z offset.

C.G. SHIFT - DELTA PAYLOADS

The general case showing LM C.G. shift by increasing D/S payload is outlined in Figure 1. The present C.G. location (Y_1,Z_1) and vehicle weight (W_1) are shown near the center line. A small weight change (ΔW) is made in a payload quadrant at some (Y_2, Z_2) location. A new C.G. location ($\bar{Y}, \bar{Z}$) will result. We are interested in (ΔY, ΔZ) and its impact on usable descent propellant.

Applying the Principle of First Moments:

$$W\bar{Y} = \int Y \, dw$$

$$(W_1 + \Delta W) \ \bar{Y} = W_1 Y_1 + \Delta W Y_2$$

substituting $\bar{Y} = Y_1 + \Delta Y$

$$(W_1 + \Delta W) \quad (Y_1 + \Delta Y) = W_1 Y_1 + \Delta W Y_2$$

$$W_1 Y_1 + W_1 \Delta Y + \Delta W Y_1 + \Delta W \Delta Y = W_1 Y_1 + \Delta W Y_2$$

Assuming: $\Delta W \Delta Y \rightarrow 0$

$$W_1 \Delta Y = \Delta W \ (Y_2 - Y_1)$$

$$\frac{\Delta Y}{\Delta W} \cong \frac{Y_2 - Y_1}{W_1} \qquad (1)$$

$$\text{and } \frac{\Delta Z}{\Delta W} \cong \frac{Z_2 - Z_1}{W_1} \qquad (2)$$

Equations (1) and (2) show that the change in C.G. location depends on the points where weight is added (Y_2, Z_2) the present C.G. location (Y_1, Z_1) and the touchdown weight of the LM (W_1).

J-MISSION CONFIGURATION

The present J-Mission LM payload configuration is shown in Figure 2. The effect of increasing LRV weight for this configuration will be discussed first since questions have arisen in this area.

The LRV is located in Quadrant I with a nominal C.G. at (-54,54) referenced to the LM center line. The LM touchdown weight (W_1) is taken as 18,000 pounds. The LM C.G. ($X_1 Y_1$) for this configuration is approximately (-.6, -1.1). Using equations (1) and (2):

$$\frac{\Delta Y}{\Delta W} \cong \frac{-54-(-.6)}{18{,}000} \cong -.003 \text{ inches/pound}$$

$$\frac{\Delta Z}{\Delta W} \cong \frac{+54-(-1.1)}{18{,}000} \cong +.003 \text{ inches/pound}$$

Adding weight to the LRV will move the LM C.G. in the -Y and +Z directions which decreases usable oxidizer and increases usable fuel. The effect of adding one pound to the LRV on LM payload capability assuming LM is at maximum capability and with propellant margins maintained is as follows:

1. Predicted unusable propellant changes -

   OX: - .003 in x 43 lb/in = -.129 lbs

   Fuel: + .003 in x 20 lb/in = +.06 lb

2. Propellant which could be offloaded -

   Fuel: .06 lb (C.G. gain)

   Fuel: .08 lb (Oxidizer unavailable $\frac{.129}{1.6} = .08$)

   Total .14 lbs.

3. Increase in inert weight -

   1.0 lb ΔW increase

   .129 lb ΔOX onboard but unavailable due to C.G. shift

   Total 1.129 lb

   Δinert weight = 1.129- .14 = .989 lb

   Propellant required for ΔV = $\frac{.989}{2}$ = .495 lb.

4. Propellant lost due to C.G. shift

   .129 (OX) +.08 (F) = .209 lb.

5. Total margin propellant lost due to adding 1.0 lb to the LRV is then:

   .495 + .209 = .704 lb.

6. A .704 margin gain requires a decrease of

   2(.704) = 1.41 lb of payload weight to return to nominal.

7. 1.4. lb (total)

   -1.00 lb (LRV)

   .41 lb (C.G. cost)

In general, the effect on payload capability will vary depending on the C.G. location (determined by configuration) and where weight is added. The C.G. effect on payload capability however will result in one of four cases. These cases are shown below using all previous assumptions, which resulted in a C.G. shift of .003 inches (Y and Z) per pound of added weight.

Case (signs refer to increase or decrease in usable propellant)	+ Fuel + OX	+ Fuel - OX	- Fuel + OX	- Fuel - OX
Payload capability change due to C.G. cost for ΔW=1 lb.	+.35	-.41	-.15	-.59

As an example, adding one pound to ALSEP for the discussed configuration decreases both usable oxidizer and fuel with payload capability being reduced .59 lb, while adding one pound to the MESA increases both usable oxidizer and fuel giving an increase of .35 lb descent payload capability.

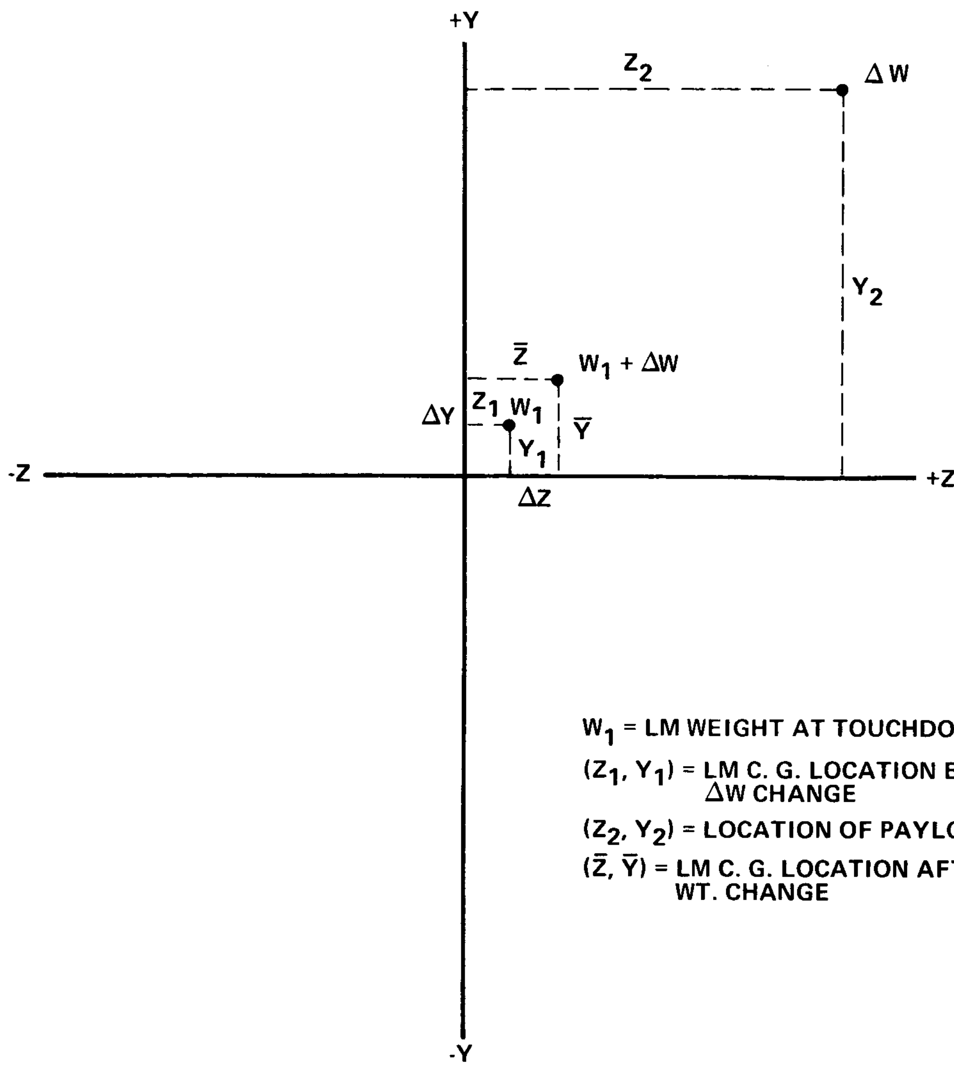
SUMMARY

It has been shown that small payload weight changes may have a significant effect on LM payload capability due to C.G. shift. The addition of one pound of payload weight will affect LM payload capability over a range encompassing an increase of .35 pounds to a decrease of .59 pounds, depending on the initial C.G. location and where payload weight is added. For the J-Mission payload configuration, the addition of one pound of weight to the LRV will reduce LM payload capability .41 pounds due to C.G. shift. If 40 pounds is added to the LRV, usable oxidizer decreases by 5.16 pounds, usable fuel increases by 2.4 pounds, and LM payload capability decreases by 16.4 pounds due to C.G. shift.

D M Duty

2032-DMD-tla D. M. Duty

Attachments
Figures 1 and 2



W_1 = LM WEIGHT AT TOUCHDOWN

(Z_1, Y_1) = LM C. G. LOCATION BEFORE ΔW CHANGE

(Z_2, Y_2) = LOCATION OF PAYLOAD

$(\bar{Z}, \bar{Y})$ = LM C. G. LOCATION AFTER PAYLOAD WT. CHANGE

FIGURE 1 - GENERAL CASE FOR LM C. G. SHIFT WITH DELTA PAYLOAD

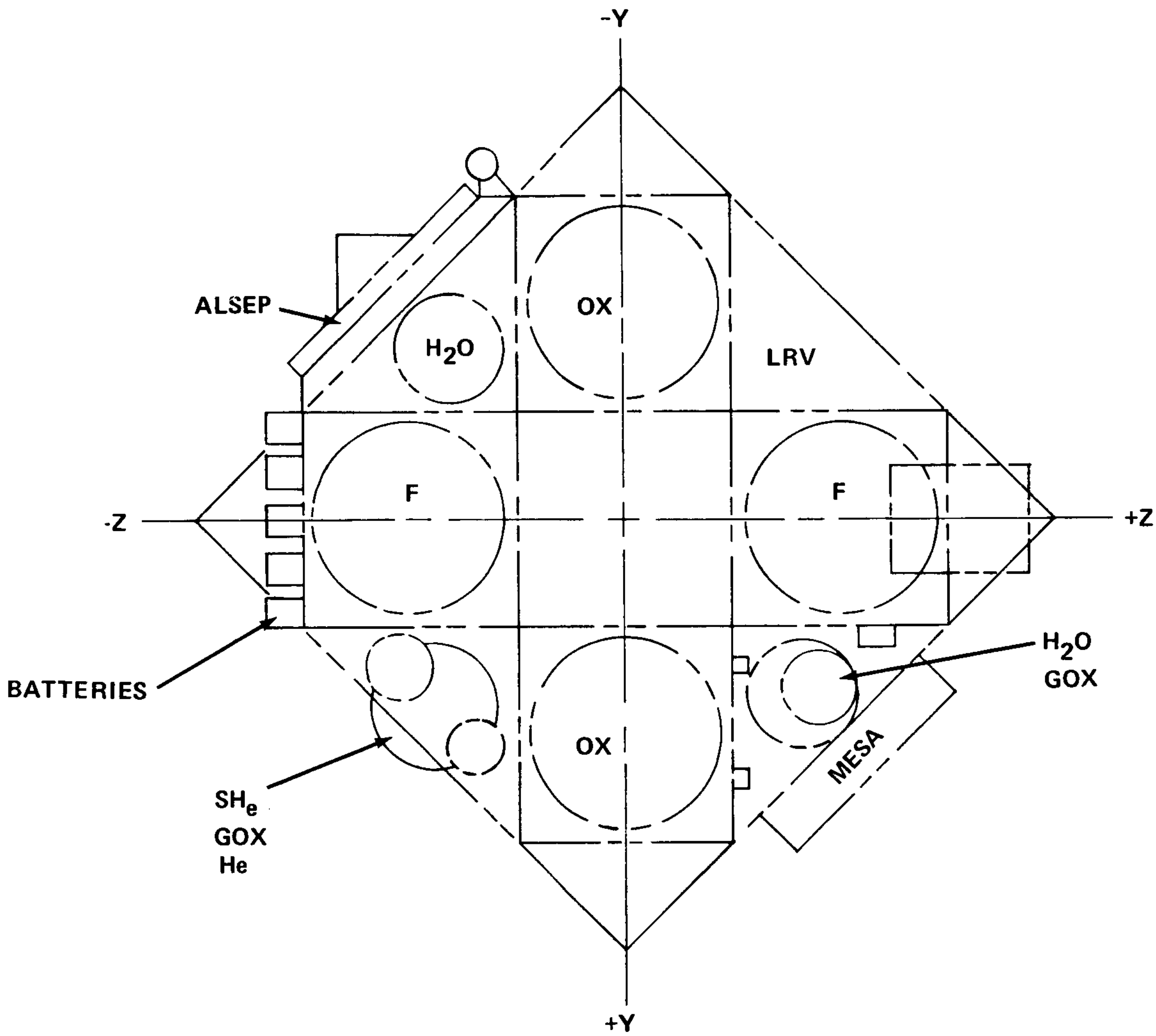


FIGURE 2 - J-MISSION LM DESCENT STAGE CONFIGURATION

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